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14. ABSTRACT

This TOP describes the techniques for operating the Bridge Crossing Simulator (BCS) at the U.S. Army Aberdeen Test Center (ATC) to support the durability testing of Military Bridging and Gap Crossing Equipment.

15. SUBJECT TERMS

Bridge Crossing Simulator Trilateral Design Test Code for Military Bridging and Gap-Crossing Equipment

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U.S. ARMY TEST AND EVALUATION COMMAND
TEST OPERATIONS PROCEDURE

*Test Operations Procedure 02-2-507 7 October 2014
DTIC AD No.

BRIDGE CROSSING SIMULATOR

UNCLASSIFIED: Distribution Statement A. Approved for public release; distribution is unlimited.

1. SCOPE.

a. This Test Operations Procedure (TOP) describes the procedures to operate the Bridge Crossing Simulator (BCS) at the U.S. Army Aberdeen Test Center (ATC), Aberdeen Proving Ground (APG), Maryland, in support of bridge durability testing using a modeling and simulation (M&S) technique. It is applicable to dry gap bridging systems. Through the use of hydraulic actuators, a reaction structure, and a control system, the BCS physically simulates vehicular crossing loads for the expected life span of the bridge undergoing testing.

b. This TOP does not address durability testing without using the BCS.

2. FACILITIES AND INSTRUMENTATION.

2.1 Facilities.

Item	Requirement
BCS	Computer-controlled hydraulic actuation system to impart simulated crossing loads on an entire bridge structure undergoing fatigue test. The BCS accomplishes this by using a load sequencing process which mimics the traversing load that a crossing vehicle imposes on a bridge structure.
Bridge test site with prepared embankments corresponding to the span and bank condition requirements of the bridge under test	Conduct real-world vehicle crossings while collecting strain data from the bridge.

2.2 BCS System Description.

The BCS is a durability test rig composed of actuators connected to whiffles, a reaction structure, and a control system; the rig is used to re-create vehicle loading on a bridge. A whiffle is a metal frame that transfers the load from the hydraulic actuator(s) to the bridge through rubber contact patches. An image of the BCS with a mounted tactical bridge, is shown in Figure 1.

Figure 1. BCS (with a bridging system mounted on top).

2.3 Instrumentation.

Devices for Measuring	Measurement Accuracy
Material strain (strain gages)	±3 microstrain
Pressure transducer	±4% of applied pressure
Force transducer	±1% of applied force
Displacement transducer	±1/8 inch
Temperature (T-type thermocouple)	±2% of full scale
Flow rate	±2% of full scale
Bridge service life monitoring system	As required
Optical instruments (video and/or still camera)	As required

3. REQUIRED TEST CONDITIONS.

3.1 Test Planning.

a. Identify participating agencies, their roles and responsibilities in testing, and the Verification, Validation, and Accreditation process.

b. Review previous test plans and test reports of bridge durability tests using the BCS.

c. Consider the following principle factors involved in configuring the BCS for a new bridge test:

(1) Bridge intended use and limitations such as bank conditions, crossing vehicles and speed regime, direction from U.S. Army Engineer School (USAES), and category representation per Operational Mode Summary/Mission Profile (OMS/MP).

(2) Span of bridge.

(3) Abutment height and slope requirements.

(4) Information resources (e.g., U.S. Army Maneuver Support Center of Excellence (MSCOE), U.S. Army Tank-Automotive and Armaments Command (TACOM), U.S. Army Tank-Automotive Research, Development and Engineering Center (TARDEC), and the U.S. Army Evaluation Center (AEC).

(5) Sample size and number of crossings required. The number of required simulated crossings to conduct fatigue testing per the Trilateral Design and Test Code for Military Bridging and Gap Crossing Equipment (TDTC) [1*] is derived based on the number of samples the test bridge is counted as. Per the TDTC, a test bridge with longitudinal and/or lateral symmetry under non-eccentric loading can be considered as 1, 2, or 4 test samples, providing the geometry and loading are identical and the onset of cracking from one sample does not influence the loading of the other sample. The more samples that the test bridge is counted as will reduce the number of simulated crossings required to gain statistical confidence that the lifetime crossing requirement will be met. AEC, the Material Developer, and the Verification, Validation, and Accreditation (VV&A) agency will determine the number of samples for the test bridge.

(6) Receipt of a developed crossing matrix that defines the crossing variables to be simulated by the BCS and number of simulated crossings.

(7) Development of a test sequence for the BCS to include the order of simulated crossings in the crossing matrix and frequency of inspections.

(8) Strain gage locations. Strain gages used for BCS operation should be placed at locations along the bridge where strain can be predicted analytically to ease drive file creation and at the planned whiffle locations. AEC and the Validation and Verification (V&V) agency must determine whether these strain gage locations will be suitable for their evaluation, and if additional strain gages are required at other locations.

(9) Run selection. AEC and the V&V agency must agree on the method that will be used to select which data will be used for simulated crossings.

(10) Durability drive file validation process. AEC and the V&V agency must agree on the method that will be used to select which data will be used for simulated durability crossings. This includes determining which strain data locations will be used for validation, whether the simulated crossing data must match the vehicle crossing data throughout the crossing or just at

*Superscript numbers correspond to Appendix D, References.

peak strain values, whether the time history strain values or fatigue damage will be the validation metric, and the simulation accuracy tolerance. Accuracy of ±3% is possible, but may be very difficult to achieve depending on the previously mentioned choices. Note that driver file is just the hydraulic actuator force versus time data used by the BCS to replicate the strain data recorded from a vehicle crossing the bridge.

(11) Mounting or assembling a bridging system on the BCS for simulated crossings requires much consideration in planning because no bridging systems are the same in design to meet their own operational requirements. However, the following factors should be considered, including, but not limited to, lift and handling equipment, manpower, geometric limitations of bridge designs, expected deflection, actuator stroke, etc.

3.1.1 Required Information on Bridge.

a. The test center will receive a Program Manager (PM)-approved crossing matrix that presents the details on the types of crossing vehicles, vehicle speeds, directions of approach, and bridge embankment configurations. Such selection process is briefly discussed as follows. Since it is not practical to replicate every live crossing on the BCS, but it is important to adequately represent full range of loads on the bridge that would be expected to occur in normal life. It is necessary to ensure that the fatigue damage associated with each applicable live crossing is represented by the subset of crossings that are simulated on the BCS. To ensure a fair and reasonable test, the live crossing data can be separated into categories of bridge abutment conditions and crossing vehicle type, and the data from each category will be plotted for fatigue life of the most critical location versus vehicle crossing speed. Fatigue damage will be averaged for a group of similar live crossing and a good fatigue life representation for the group, and the live crossing with strain data closest to the averaged fatigue damage for the group will be selected for the simulated run. It is necessary to scale the strains from the selected crossings to result in fatigue damage equivalent to the group average. Damage averaging technique is considered a reasonable approach as the analysis of a bridge fatigue test simulation is a fatigue life test of which the primary objective is to determine the fatigue damage the bridge can withstand before a durability failure.

b. For demonstration, Table 1 presents a typical layout of information that completed the Run Selection Process, and was selected for a crossing matrix for the Durability Test of a tactical bridge.

TABLE 1. VEHICLE CROSSING FILES SELECTED FOR SIMULATION

FILE NAME	SPEED, miles per hour (mph)	VEHICLE	TRAVERSE DIRECTION
Bank Condition: Level			
Run036	3	MLC70T (tracked)	BA
Run046	6		AB
Run055	9		AB
Run060	9		BA
Run064	12		BA
Run071	15		AB
Run155	3	MLC96W (wheeled)	AB
Run181	9		AB
Run227	6		AB
Run250	12		AB
Run262	15		AB
Run269	15		BA
Bank Condition: Racked, Strain Channel 2 High			
Run307	3	MLC70T (tracked)	AB
Run331	9		AB
Run359	15		AB
Run430	12	MLC96W (wheeled)	BA
Run434	12		AB
Run447	3		BA
Bank Condition: Side Slope, Even Strain Channels High			
Run505	3	MLC96W (wheeled)	AB
Run516	9		BA
Run534	12		AB
Run548	3	MLC70T (tracked)	BA
Run575	9		BA
Run590	12		BA

3.1.2 Predictive Modeling.

Predictive modeling of vehicle crossing results must be done using weight distribution data for the crossing vehicles and the bridge information provided by the customer. In general, statics will be used to determine equations for moments and deflections based on the specific bridge. For a bridge whose primary structural members are simply supported beams (L), the beam equations (1) and (2) derived from Figure 2 can be used to calculate the moment contribution at a location (x) due to a particular axle weight (P) and location (a).

$$M(x) = \frac{L-a}{L} Px, \quad where \quad 0 \leq x < a \qquad \text{Equation 1}$$

$$M(x) = \frac{a}{L} P(L-x), \quad where \quad a < x \leq L \qquad \text{Equation 2}$$

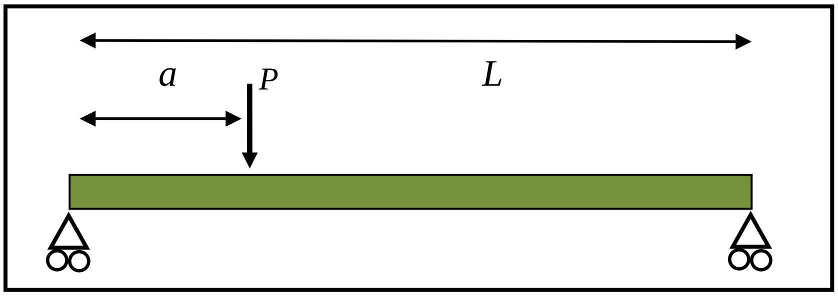


Figure 2. Simply supported beam with point load.

The total moment at any location can be calculated from the superposition of the contributions of each axle.

For the BCS application, the total moment (M_a) at a location (L_a) will be calculated using Equation 3, which can be expressed in terms of whiffle's forces (F_i), their corresponding locations (L_i), and the bridge's length (L) as follows:

$$M_a = \sum_{i=1}^{a} F_i L_i \left(1 - \frac{L_a}{L}\right) + \sum_{i=a+1}^{L} F_i L_a \left(1 - \frac{L_i}{L}\right) \qquad \text{Equation 3}$$

The results of a crossing can be predicted by solving for the moments due to the crossing vehicle at small (6 inch or less) increments along the bridge. The same process as described in paragraph 4.2.2 can then be used to predict actuator forces during the crossing from the calculated moments. These models will be used for the following:

a. Determine the number of actuators and locations. If it is predicted that the current BCS configuration will not satisfactorily replicate the vehicle crossings, the number and layout of actuators in the predictive model can be changed until a suitable configuration is found.

b. Calculate bridge deflection in the predictive model to determine an appropriate abutment height for the BCS. Total bridge deflection is the sum of those due to the dead weight of the bridge plus that of the crossing vehicle and is calculated from Equation 4. The moment on the bridge (M) is integrated twice to solve for deflection (v). When determining abutment height, it is important to consider the additional vertical clearance required by the bridge during the side slope configuration.

$$v = \frac{1}{EI} \int \int M dx \qquad \text{Equation 4}$$

c. Use bridge deflection, plus that of the BCS structure, to calculate required total actuator stroke for each actuator location compared with the capabilities of the existing actuators. When doing this comparison, it is desirable that the existing actuators' stroke exceed the required actuator stroke plus the stroke required to accommodate changing the abutment configuration from one side slope condition to the opposite side slope. If the existing actuators' stroke does not exceed this total, there are several possible solutions:

(1) Purchase new actuators for locations where the existing actuators do not exceed the expected stroke requirement.

(2) Add or remove spacers to actuators during testing whenever changing to/from the side slope configuration.

(3) Coordinate with AAO, the U.S. Army Test and Evaluation Command (ATEC), and the customer to determine whether the side slope crossings can be replaced with level crossings.

3.1.3 Verification and Validation (V&V) Plan.

a. For each use of the BCS, to determine the durability of a bridge, a V&V plan is required and will be developed in accordance with ATEC Regulation 73-21[2] to establish the framework for how the BCS will be used according to the guidance stated in the TDTC.

b. The document will include the information and procedures necessary to verify and validate the test center's BCS for use in the durability of the test specimen. The BCS will simulate vehicle crossings, and for these simulations to be valid it must be shown that fatigue damage imparted to the bridge for the BCS is commensurate with the damage from vehicle crossings. In addition, the plan will also include, but not be limited to, the participating agencies and their V&V responsibilities as well as the plan's intended use and limitation of M&S.

c. BCS accreditation must be completed when results are used in an ATEC evaluation. AMSAA will coordinate V&V and accreditation with the AEC accreditation action officer (AAO). V&V results will be provided to the AEC AAO for inclusion in the accreditation report/request.

3.2 Test Preparation.

3.2.1 BCS Configuration Setup.

There are three main types of configuration: Level-Level, Side-Sloped, and Racked. Level-Level means the bridge is set perfectly level. Side-Sloped indicates that opposite ends of the bridge are tilted in the same lateral direction. Racked means opposite ends of the bridge are tilted in different directions. In addition, the degree to which the system is to be configured depends on the type of bridge as prescribed in the TDTC. The exact procedure for the BCS configuration may vary from bridge to bridge. However, all bridges follow a basic form of installation.

a. Moving End Abutments. The bridge will need a safety margin at both end abutments. The BCS abutment gap must be changed to match the test requirements of the test specimen.

b. Abutment Height. Raise the abutment height greater than the maximum deflection of the test specimen plus any additional height that may result from the abutment configuration of the test item other than level-to-level (i.e., side sloped or racked).

c. Actuator Position. Position actuators according to predictive model plan.

d. Calibrate the BCS data acquisition (DAQ) and control devices such as load cells and displacement transducers, and zero the whiffles.

(1) DAQ. The electronics of the DAQ must be calibrated to preserve its functional fidelity. All circuit boards (e.g., conditioners) of the BCS controller electronics must be calibrated by Certified Calibration Laboratory standards in accordance with Army Regulation 750-43[3].

(2) Load cells. The actuators are equipped with load cells and are force-generating devices. Calibration of load cell(s) can be performed either off-site by the load cell manufacturer or on-site during the test activity by using a certificate-calibrated load cell and calibration fixture.

(3) Displacement transducer. The device provides an indication of the actuator piston rod displacement.

(4) Zeroing whiffles. The process ensures that whiffles rest weightless on the test specimen and that the applied force on the bridge is only the force actually imparted to the bridge by the BCS. The recommended process to zero the weight of the whiffle involves adjusting the zero offset of the load cell signal conditioners to negate the whiffle's weight after raising the whiffle off the bridge with the actuators. The whiffle zeroing can be generalized in the following steps:

(a) Once the bridge has been placed on the BCS and the whiffles have been placed on the bridge and secured properly to the actuators, and ensure that the whiffle are resting on the bridge

(b) Raise the whiffle off the bridge by extending the actuators.

(c) Initiate the offset zero to zero and obtain the conditioner output values.

(d) Complete the whiffle zeroing by placing the negative conditioner output values into the offset zero.

(e) Lower the whiffle slowly to the bridge.

3.2.2 Bridge Instrumentation.

a. Install strain gage instrumentation. Since the BCS is designed to reproduce induced strains associated with a vehicle crossing a bridge, the same gages, in identical locations, will be used to record strain data during both vehicle crossings and simulated durability crossings. The number of gages would be, at a minimum, equal to the number of actuators and, if the BCS data acquisition (DAQ) system (i.e., channels) permits, to the number of the bridge's load bearing members and fatigue critical areas, such as I-beams or chords.

b. For example, the BCS which used 20 hydraulic actuators to recreate vehicle loading on a bridge for a durability test employed 20 strain gages to replicate the strain data recorded from a vehicle crossing the bridge. Strain gages were bonded to each inner chord at the approximate lengthwise location of a hydraulic actuator on the BCS. The vertical location of strain gages should be positioned at the maximum stress of the structural members. For bridging systems consisting of I-beams, the strain gages are normally located at the bottom of the I-beams as shown in Figure 3.

Figure 3. Cross section of a bridge with left and right strain gage locations ε_L and ε_R.

c. Install string potentiometers at the center of the bridge gap to measure deflection.

4. TEST PROCEDURES.

4.1 Vehicle Crossings.

Vehicle crossing procedures will not be covered in this TOP; vehicle test operation is addressed in TOP 09-2-027[4]. During the vehicle crossings, however, the following information must be collected, documented, and reported, at a minimum, to warrant the qualitative outcomes for the simulation testing.

a. Bridge components must be uniquely identified, and their locations in the bridge during vehicle crossings must be documented. The bridge will then be reassembled on the BCS with components in exactly the same order and locations as documented during vehicle crossings to allow for creation of accurate drive files.

b. As a good practice and sanity check, the strain due to the dead weight of the bridge should be measured. Measurements should be taken from strain gages prior to the bridge assembly and after the bridge deployed. The differences between the unsprung and sprung masses of the bridge can be predicted using the predictive modeling calculation (paragraph 3.1.2b).

c. Prior to conducting vehicle crossings, it is important to record strain data from the placement of a known load at multiple known locations on the bridge. If a known load of sufficient weight is unavailable, a crossing vehicle of known weight distribution can be substituted. By comparing the collected strain data with the data from the predictive model, adjustments can be made to the model to ensure its accuracy. However, prior to making changes to the predictive model, the setup and accuracy of the strain gage instrumentation should be checked.

d. During the conduct of vehicle crossings, collected strain data must be validated daily.

(1) The instrumentation used to collect the strain data should be checked at the beginning of the day and the end of the day. This should be done by recording strain data while a crossing vehicle of known weight distribution is parked at several marked locations on the bridge. Markings should consist of squares for tracks or tires to allow easy measurement of the vehicle's position relative to the markings. The strain values from the beginning of the day and the end of the day should be compared with any previous results.

(2) As part of the validation process, collected strain data must be compared with predictive model results for the crossing conditions.

e. Upon completion of vehicle crossing, the collected and validated strain data will undergo a run selection process.

(1) Use strain data from vehicle crossings of rated military load classification (MLC) tracked and wheeled vehicles acquired for the various dynamic conditions tested. Select only files with a complete set of data (all actuator strain channels functional). Segregate the crossings into categories, with each category corresponding to vehicle type and gap/embankment geometry.

(2) Further analysis will be conducted for selection of representative data runs. The analysis consists of plotting the data from each category in the format of fatigue life of the most critical location versus vehicle crossing speed. Clusters of data are identified on the plots, and the crossings that correspond to the average fatigue life of the regime are identified within the cluster. Each cluster is represented by the single crossing that coincided with the average of the fatigue lives repeated for as many times as there are runs in the cluster. The net effect of the grouping is to reduce the number of individual drive files executed during the simulation. The same procedure is repeated for each vehicle type and gap/embankment geometry. A distribution of simulated bridge crossings by vehicle type and crossing conditions is proposed to the ATEC System Team (AST) for evaluated programs in the form of a matrix. The matrix is used to define the number of iterations to perform each selected crossing during the simulation.

4.2 Simulated Crossings.

4.2.1 Install Bridge and Whiffles.

a. Install bridge on BCS:

(1) Assemble the test item in accordance with the test sponsor representative's guidance on-site or by referring to the Operator's Manual. In addition, assemble the bridge components (e.g., modules) in exactly the same locations and order as they were during vehicle crossings. If the system's launcher is not available, a mobile crane can be used to position the assembled bridge over each prepared gap.

(2) Connect DAQ equipment to the installed strain gages to collect and store real-time strain data.

(3) Install string potentiometers at the bridge's mid-span (worst deflection) to measure its maximum deflection. In addition, the displacement of the bridge at abutments should also be measured to determine the actual deflection of the bridge's mid-span.

b. Install whiffles, which are metal frames that transfer the load from the hydraulic actuator(s) to the bridge through rubber contact patches.

4.2.2 Drive File Creation.

There are multiple ways to create the drive files that will be used to conduct the simulated crossings.

a. Strain control functionality is built into the ATC BCS control system, which operates a real-time feedback loop for each actuator (independent of the others) to match strain gage data from the bridge (i.e., simulation crossings) to strain data recorded during a vehicle crossing by controlling actuator forces. In the past, this method has been followed to create the drive files used during durability testing. Drive files created in this way include significant noise because the actuators are not synchronized, which makes the files extremely difficult to compress if the bridge under test has long clear span (i.e., significant dynamic deflection under loading of vehicle crossings and high demand of hydraulic flow rate) coupling with less damping effect of the reaction structure due to a low viscosity of the simulator's working fluid.

b. Another way to create drive files is to construct the files based solely on the characteristics of hypothetical vehicles used for the rating of the MLC of the vehicles and bridges characteristics, which are presented as Appendix C of the TDTC. This method would not include the impact factor which normally applies to an induced static load to give the equivalent induced dymamic loads caused by the load's movement. In the absence of its live crossing data, this method could only used for simulated caution crossing.

c. Drive files of a MLC can also be fictitiously created by multiplying the low MLC by an up-scaled factor to yield a higher MLC of the same class. For example, a fictitious MLC40 Bradley vehicle can be created by using a Bradley load drive file (MLC30) and increasing the loads by a factor of 4:3. Note that MLC and load of application are not necessarily linearly proportional to each other. To determine the scale factor, one should consult TARDEC for guidance.

d. Drive files can be created by using a script in MATLAB that utilizes the vehicle crossing data to directly create a drive file, resulting in a file which is much smoother than that created using strain control. This also allows the drive file to be compressed, yielding time savings of up to 50 percent compared with non-compressed simulated crossings.

(1) The script uses an NxN coefficient matrix (A) representing the relationship between a whiffle force and its strain effect on a whiffle location, multiplied by a vector of N unknown whiffle forces (F) at one instant in time, equal to a moment vector (M) calculated from the strain data at the same instant in time. This is shown as Equation 5. The script solves for the unknown force vector (F) using the non-linear equation solver for each row of strain data and saves the forces as the drive file.

$$[A][F] = [M]\,, \qquad \text{Equation 5}$$

The moment values will be calculated using Equation 6 for each strain gage. The moment vector values will be the sum of the moment values at each whiffle location.

$$M_n = \frac{EI\varepsilon_{n,}}{y}\,, \qquad \text{Equation 6}$$

Where: E is the Young's modulus for the bridge’s material
I is the moment of inertia for the beam cross section
y is the distance of the strain gage from the beam neutral axis
ε is the strain value at location n

(2) The A matrix coefficients are best determined experimentally by applying a steadily increasing load to the bridge with a single whiffle while recording strain and force data from the BCS. Because force and strain are known, the A-matrix coefficients for that location can be determined.

(3) To calculate actuator forces from whiffle forces, determine the ratio for the moment contributions of the left and right beams at each whiffle location. Use these ratios to divide the whiffle force among the left and right actuators for each whiffle. It is desirable that the difference between applied forces for the actuators of a whiffle be less than the amount that will create an unbalanced moment on the whiffle. This unbalanced moment will cause one side of the whiffle to lift off the bridge, leading to the whiffle’s “walking” out of its desired position.

(4) The newly created drive file is run at 50 percent amplitude on the BCS to determine whether the BCS control system can execute the file. The performance of the BCS and drive file is plotted as shown in Figure 4 for each actuator and its corresponding strain gage. The comparison of force command with force feedback is used to identify whether the BCS control system gains are suitable. For example, if the force feedback lags behind command, then

gains should be increased, whereas if "ringing" (i.e., due to unstable system operation) is in the force feedback data, gains may need to be decreased. Once force command and feedback are in agreement, any discrepancies between the simulated crossing strain data and the vehicle crossing strain data must be corrected. Correction is done by adjusting the A-matrix coefficients, creating a new drive file, running it on the BCS, and repeating the comparison.

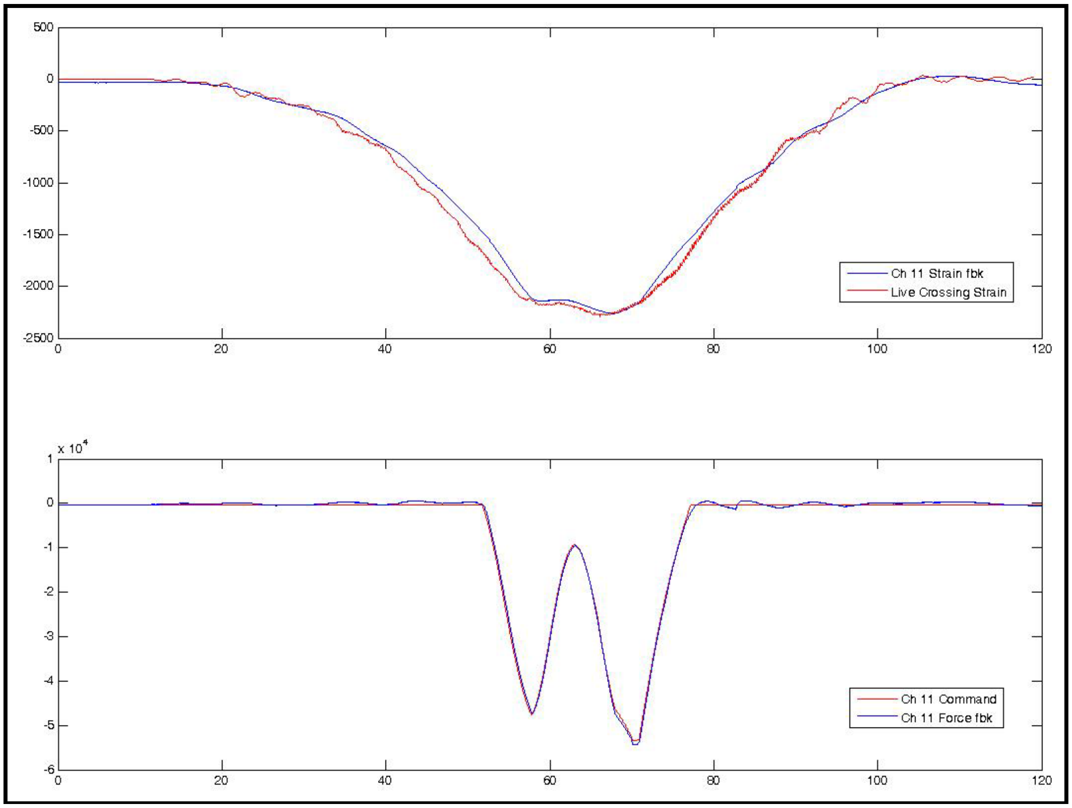


Figure 4. Typical plot for performance evaluation of a strain/actuator location.

(5) Once the difference between strain ranges for the simulated and vehicle crossings is less than the threshold specified by the AAO, the simulated crossing is rerun while actuator displacement is recorded. The resulting displacement data are processed by a flow optimization script that calculates the total actuator hydraulic fluid flow rate at each sample period based on the change in displacements. For every 10 data points, the total demanded flow rate is compared with the available flow rate of the hydraulic power unit to determine the percent of flow utilized. This percent utilization factor is used as a decimation factor for the 10 corresponding data points of the drive file data using the 'interp1' routine in MATLAB. The decimated drive file data are then appended to the previously decimated data, and the script starts processing the next 10 sample periods of data. Typically, the resulting drive file shows some compression in the beginning of the run and the most compression in the middle, compared with the 60- to 180-second drive file.

(6) The compressed drive file will be run on the BCS, scaled, and rerun until the strain ranges for critical channels are within the AAO specified tolerance.

4.2.3 Executed Simulated Crossings.

a. General Startup. The following checklist must be reviewed and completed prior to startup operations:

(1) Actuator flow valves.

(2) DAQ checks.

(3) Servo controller gains.

(4) Limit detectors.

(5) Hydraulic fluid reservoir level.

(6) Heat exchanger valves open.

(7) Fluid reservoir valves open.

(8) Diesel engine oil level.

b. General Shutdown. Once the test session is completed, it is essential to shut down the BCS system in accordance with the following five-step procedure.

(1) Shut down the pressure.

(2) Shut down the engine.

(3) Shut down the BCS controller software.

(4) Power down the BCS controller.

(5) Perform preventive maintenance checks and services (PMCS) on the cooling fans, hydraulic lines, and actuators for damage and leaks.

4.3 Inspections.

a. BCS.

(1) Inspect the position of whiffles on the bridge. Data quality checks, as described in paragraph 4.3.c, will be performed to identify whether a reposition of the whiffles is necessary. If the whiffles are not within their initially marked boundaries on the bridge, adjust

their positions accordingly by using their associated actuators if they are connected, or a mobile crane if they are not.

(2) Inspect highly loaded components such as actuator swivel joints and mounts for cracks or loose bolts. Bolts at highly stressed locations should be marked with a line across the bolt head and the surrounding surface when torqued, allowing for visual detection of bolt loosening.

b. Bridge System Under Test. Each bridge design is unique and one-of-a kind in its own commodity and application. Therefore, a separate inspection plan has to be developed by the test center to address its unique design characteristics. The inspection plan should be written in accordance with the bridge's Fracture Control Plan which is normally included in the bridge's Technical Manual. A typical checklist for a bridge inspection is provided as Appendix A of the TOP.

(1) Employ Appendix A as a procedural guideline for the bridge inspection plan and procedures.

(2) Document inspection results in the provided forms (Appendix A).

c. Data Quality Checks. Bridge strain data, actuator force, and actuator displacements should be recorded for every simulated crossing. At least hourly, compare the values in the collected data with the results previously collected for that drive file. Issues to check for include strain gage other instrumentation failure, whiffle out of position, and accidental use of a drive file different from that intended.

4.4 Failure Definition.

Refer to the Failure Definition/Scoring Criteria (FD/SC) for the system to determine the proper classification of any failures that occur during testing. In many instances, it may be desirable not to repair damage to the bridge that occurs during extended durability testing. Other considerations may take precedence (i.e., verification of damage tolerant design).

5. DATA REQUIRED.

5.1 Vehicle Crossings.

a. Description of test setup, to include span and bank conditions. Photographs should be taken for documentation.

b. Description of crossing vehicle type and load class.

c. Crossing vehicle speed.

d. Material strains.

e. Bridge deflection.

f. Whiffle movements.

g. Number of crossings conducted with each vehicle type.

h. Description of any damage noted during bridge inspections.

i. Results of periodic strain and deflection checks conducted as part of inspection procedures.

5.2 Simulated Crossings.

a. Description of test setup to include span and bank conditions. Photographs should be taken for documentation.

b. Description of crossing vehicle drive file to be used.

c. Material strains.

d. Bridge deflection.

e. Actuator forces.

f. Number of simulated crossings conducted with each drive file.

g. Description of any damage noted during bridge inspections.

h. Video of test conduct, if required, showing entire bridge or critical areas as applicable.

6. PRESENTATION OF DATA.

6.1 Test Data Management.

a. Prepare time history files of bridge strain and deflection for vehicle and simulated crossings and place on suitable media (i.e., compact disk (CD)) for dissemination to other parties.

b. Prepare selected hard copies of bridge strain and deflection data for field and simulated crossings as will be necessary for the Final Report.

c. Prepare results from periodic inspections and organize results into graphical, tabular, and narrative formats as appropriate.

d. Organize test photographs and video presentation. Prepare files for electronic distribution.

e. Post all pertinent test data to a distributed access site such as the ATC Versatile Information Systems Integrated On-Line (VISION) site.

6.2 Test Data Illustration.

A sample set of test data extracted from the Durability Test of a tactical bridge is provided in Tables 3 through 6, and Figure 5, to demonstrate the use of applicable data forms and the processed test data flow.

TABLE 3. LIVE CROSSINGS.

SPEED, mph	NO. OF CROSSINGS			
	M1A1 MBT	M1A1 WITH MINE PLOW	HETS WITH M1A1 MBT	TWO M1A1 MBTs, MLC 80,100-FT SPACING
Level Gap				
3	16	12	32	8
6	16	12	26	0
9	16	12	26	0
12	12	12	31	0
13	0	0	9	0
15	12	10	9	0
Total	72	58	133	8
Racked Gap				
3	12	0	24	10
6	12	0	24	0
9	12	0	24	0
12	12	0	14	0
15	13	0	6	0
Total	61	0	92	10
Side Slope Gap				
3	12	0	14	6
6	12	0	12	0
9	12	0	12	0
12	12	0	12	0
15	12	0	0	0
Total	60	0	50	6

TABLE 4. VEHICLE CROSSING FILES SELECTED FOR SIMULATION.

FILE NAME	SPEED, mph	VEHICLE	TRAVERSE DIRECTION
Bank Condition: Level			
Run036	3	M1A1 MBT	BA
Run046	6		AB
Run055	9		AB
Run060	9		BA
Run064	12		BA
Run071	15		AB
Run155	3	HETS with M1A1 MBT	AB
Run181	9		AB
Run227	6		AB
Run250	12		AB
Run262	15		AB
Run269	15		BA
Bank Condition: Racked, Strain Channel 2 High			
Run307	3	M1A1 MBT	AB
Run331	9		AB
Run359	15		AB
Run430	12	HETS with M1A1 MBT	BA
Run434	12		AB
Run447	3		BA
Bank Condition: Side Slope, Even Strain Channels High			
Run505	3	HETS with M1A1 MBT	AB
Run516	9		BA
Run534	12		AB
Run548	3	M1A1 MBT	BA
Run575	9		BA
Run590	12		BA

TABLE 5. SIMULATED CROSSINGS DRIVE FILE CREATION

M1A1 MBT		HETS WITH M1A1 MBT	
FILE NAME	QUANTITY	FILE NAME	QUANTITY
Run036	165	Run155	32
Run046	63	Run181	97
Run055	42	Run227	15
Run060	24	Run250	29
Run064	37	Run262	35
Run071	17	Run269	32
Run307	42	Run430	49
Run331	25	Run434	62
Run359	22	Run447	26
Run548	15	Run505	40
Run575	29	Run516	19
Run590	13	Run534	48
Total:	494	Total:	484

TABLE 6. BCS SIMULATED CROSSINGS

NO.		TOTAL DURABILITY CROSSINGS	RUN NO.	DIRECTION	VEHICLE	BANK CONFIG	SPEED, mph	TIME	
SET	CROSSINGS							START	STOP
30 April 2012									
1	26	1,656	36	BA	M1A1 MBT	Level	3	11:23	11:39
2	26	1,682	36	BA	M1A1 MBT		3	11:40	11:56
3	26	1,708	71	AB	M1A1 MBT		15	11:57	12:20
4	26	1,734	71	AB	M1A1 MBT		15	12:21	12:44
5	25	1,759	269	BA	HETS/M1A1 MBT		15	12:45	13:15
6	25	1,784	269	BA	HETS/M1A1 MBT		15	13:16	13:45
7	25	1,809	262	AB	HETS/M1A1 MBT		15	13:46	14:17
8	25	1,834	262	AB	HETS/M1A1 MBT		15	14:17	14:48
9	25	1,859	155	AB	HETS/M1A1 MBT		3	15:11	15:39
10	25	1,884	155	AB	HETS/M1A1 MBT		3	22:41	23:09
11	25	1,909	181	BA	HETS/M1A1 MBT		9	23:17	23:44
1 May 2012									
12	25	1,934	181	BA	HETS/M1A1 MBT	Level	9	23:50	00:27
13	25	1,959	155	AB	HETS/M1A1 MBT		3	00:45	01:12
14	25	1,984	155	AB	HETS/M1A1 MBT		3	01:30	01:48
15	25	2,009	181	BA	HETS/M1A1 MBT		9	07:49	08:14
16	25	2,034	181	BA	HETS/M1A1 MBT		9	08:14	08:45
17	25	2,059	46	AB	M1A1 MBT		6	08:45	09:02
18	25	2,084	46	AB	M1A1 MBT		6	09:02	09:18
19	25	2,109	64	BA	M1A1 MBT		12	09:20	09:43

APPENDIX A. TYPICAL BRIDGE INSPECTION CHECKLIST.

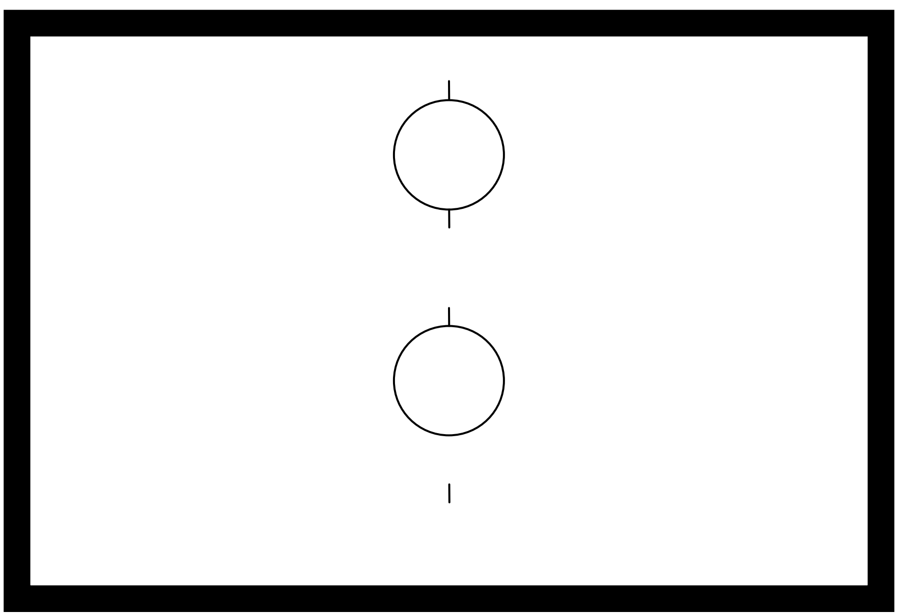
DATE: ___________________________
LAST CROSSING #: ________________

LEVEL 1 INSPECTION: Fatigue Monitor Gauge
CONDUCT EVERY 500 CROSSINGS ON EVERY MODULE

MODULE	INITIALS	Crack First Fatigue Monitor Gauge Description	
		ODD SIDE	EVEN SIDE
I			
II			
III			
IV			
V			
VI			
VII			
VIII			

Check extent of cracking in central area between two holes and from the holes to the outside edges of monitor.

Use the diagram below to sketch the approximate crack characteristics.



APPENDIX A. TYPICAL BRIDGE INSPECTION CHECKLIST.

DATE: ___________________________
LAST CROSSING #: ________________

LEVEL 1 INSPECTION: BRIDGE SKIN
CONDUCT EVERY 500 CROSSINGS ON EVERY MODULE

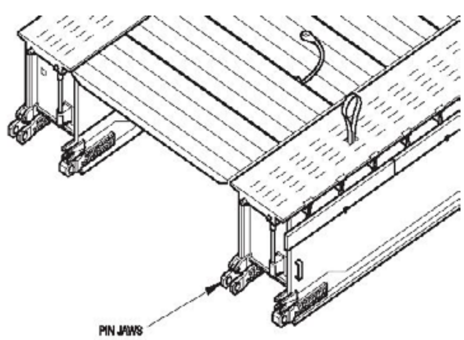
MODULE	INITIALS	EVIDENCE OF EXTERNAL DAMAGE		
		ODD CHORDS	EVEN CHORDS	TRANSVERSE COMPONENTS
I				
II				
III				
IV				
V				
VI				
VII				
VIII				

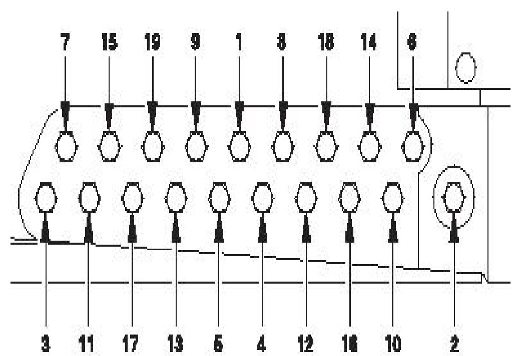
Check the skin of the chords and transverse components. Take photographs of any evidence of external damage to the bridge skin.

APPENDIX A. TYPICAL BRIDGE INSPECTION CHECKLIST.

DATE: ____
LAST CROSSING #: ______________________________
LEVEL 1 INSPECTION: Rotabolts
CONDUCT EVERY 500 CROSSINGS ON EVERY MODULE

MODULE	INITIALS	Rotabolt Loose or Damaged			
		Odd-Outer	Odd-Inner	Even-Inner	Even-Outer
I					
II-A					
II-B					
III-A					
III-B					
IV-A					
IV-B					
V-A					
V-B					
VI-A					
VI-B					
VII-A					
VII-B					
VIII					





Check bolts for signs of damage.
Grip each bolt as tight as a pen and attempt to rotate. If loose, note the bolt number and location.

APPENDIX A. TYPICAL BRIDGE INSPECTION CHECKLIST.

DATE: ____

LAST CROSSING #: _________________________________
LEVEL 2 INSPECTION: Bottom Chord Weld
CONDUCT EVERY 500 CROSSINGS ON EVERY MODULE WHERE GAUGE HAS CRACKED ALONG THE LENGTH BETWEEN THE TWO GAUGE HOLES.

Initial	Module	Location	Description

Check for cracks propagating transversely away from the bottom of an inner and outer chord's intersecting weld.

APPENDIX A. TYPICAL BRIDGE INSPECTION CHECKLIST.

DATE: ____
LAST CROSSING #: ___________________________________
LEVEL 2 INSPECTION: Gauge Vertical Weld Toes
CONDUCT EVERY 500 CROSSINGS ON EVERY MODULE WHERE GAUGE HAS CRACKED ALONG THE LENGTH BETWEEN THE TWO GAUGE HOLES.

Initial	Module	Location	Description

Check for cracks propagating at the gauge vertical weld toes.

APPENDIX A. TYPICAL BRIDGE INSPECTION CHECKLIST.

DATE: ____
LAST CROSSING #: ______________________________
LEVEL 2 INSPECTION: End Diaphragm Vertical Weld Toes
CONDUCT EVERY 500 CROSSINGS ON EVERY MODULE WHERE GAUGE HAS CRACKED ALONG THE LENGTH BETWEEN THE TWO GAUGE HOLES.

Initial	Module	Location	Description

Check for cracks propagating along or away from the vertical welds at the end diaphragm.

APPENDIX A. TYPICAL BRIDGE INSPECTION CHECKLIST.

DATE: ____
LAST CROSSING #: _________________________________
LEVEL 2 INSPECTION: Bore of Jaw Pin Holes
CONDUCT EVERY 500 CROSSINGS ON EVERY MODULE WHERE GAUGE HAS CRACKED ALONG THE LENGTH BETWEEN THE TWO GAUGE HOLES.

Initial	Module	Location	Description

Check for any evidence of cracks propagating from the bore of the jaw pin holes.

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APPENDIX B. GLOSSARY.

Term	Definition
Bridge Crossing Simulator	Simulates the rolling loads applied by a moving vehicle with a system of hydraulic actuators and loading fixtures.
drive file	Each vehicle crossing will have a drive file created containing the necessary actuator force over time command to replicate the vehicle crossing strain data.
end abutment	The part of the Reaction structure that can be adjusted to support the bridge at either end.
hydraulic actuator	The single-ended double-acting actuators that are heavy duty and fatigue resistant. They are mounted in the reaction structure with swivel mounting fixtures.
knuckle	The hinged part of the actuator that connects to the whiffle.
level	Simulation conditions in which opposite corners of the bridge are level and then put under a load.
load cell	Part of the actuator electronics that provides force feedback information.
MATLAB	A high level technical computing language and interactive environment for algorithm development, data visualization, data analysis, and numeric computation. MATLAB has a wide range of applications, including signal and image processing, communications, control design, test and measurement, financial modeling and analysis, and computation biology.
racked	Simulation condition in which diagonal corners of the bridge are raised and then put under a load.
reaction structure	Large steel frame that holds the bridge and the actuators.
servo valve	The actuators are equipped with multistage servo valves that control the direction and amount of fluid flow to the actuators.

APPENDIX B. GLOSSARY.

Term	Definition
side-slope	Simulation condition in which the bridge is rotated about the longitudinal axis and then put under a load.
strain gage	An electronic device that provides strain feedback information.
turnbuckle	A device for adjusting the tension chains. It consists of two threaded eyelets, one screwed into each end of a small metal loop, one with a left-hand thread and the other with a right-hand thread.
whiffle	Metal frame that transfers the load from the hydraulic actuator(s) to the bridge through rubber contact patches.

APPENDIX C. ABBREVIATIONS.

AAO	accreditation action officer
AEC	U.S. Army Evaluation Center
AMSAA	U.S. Army Materiel System Analysis Activity
APG	Aberdeen Proving Ground
AST	ATEC System Team
ATC	U.S. Army Aberdeen Test Center
ATEC	U.S. Army Test and Evaluation Command
BCS	Bridge Crossing Simulator
CD	compact disk
DAQ	data acquisition
FD/SC	Failure Definition/Scoring Criteria
HETS	Heavy Equipment Transporter System
M&S	Modeling and Simulation
MBT	main battle tank
MLC	military load classification
mph	miles per hour
MSCOE	U.S. Army Maneuver Support Center of Excellence
OMS/MP	Operational Mode Summary/Mission Profile
PM	Program Manager
PMCS	preventive maintenance checks and services
TACOM	U.S. Army Tank-Automotive and Armaments Command
TARDEC	U.S. Army Tank-Automotive Research, Development and Engineering Center
TDTC	Trilateral Design and Test Code for Military Bridging and Gap-Crossing Equipment
TOP	Test Operations Procedure
TR	technical report
USAES	U.S. Army Engineer School
V&V	Verification and Validation
VISION	Versatile Information Systems Integrated On-Line
VV&A	Verification, Validation and Accreditation

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APPENDIX D. REFERENCES.

1. ATEC Regulation 73-21 Accreditation of Test and Evaluation Technologies – Models, Simulations, Instrumentation, 10 July 2013.

2. Trilateral Design and Test Code for Military Bridging and Gap-Crossing Equipment, FRG, U.K., U.S.A., January 2005.

3. AR 750-43 Army Test, Measurement, and Diagnostic Equipment, 14 December 2004.

4. TOP 09-2-027, Bridges and Equipment, 15 September 2009.

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APPENDIX E. APPROVAL AUTHORITY.

CSTE-TM 7 October 2014

MEMORANDUM FOR

Commanders, All Test Centers
Technical Directors, All Test Centers
Directors, U.S. Army Evaluation Center
Commander, U.S. Army Operational Test Command

SUBJECT: Test Operations Procedure (TOP) 02-2-507, Bridge Crossing Simulator, Approved for Publication

1. TOP 02-2-507, Bridge Crossing Simulator, has been reviewed by the U.S. Army Test and Evaluation Command Test Centers, the U.S. Army Operational Test Command, and the U.S. Army Evaluation Center. All comments received during the formal coordination period have been adjudicated by the preparing agency. The scope of the document is as follows:

This TOP describes the procedures to operate the Bridge Crossing Simulator at the U.S. Army Aberdeen Test Center, in support of bridge durability testing using a modeling and simulation technique. It is applicable to dry gap bridging systems. Through the use of hydraulic actuators, a reaction structure, and a control system, the Bridge Crossing Simulator physically simulates vehicular crossing loads for the expected life span of the bridge undergoing testing.

2. This document is approved for publication and has been posted to the Reference Library of the ATEC Vision Digital Library System (VDLS). The VDLS website can be accessed at https://vdls.atc.army.mil/.

3. Comments, suggestions, or questions on this document should be addressed to U.S. Army Test and Evaluation Command (CSTE-TM), 2202 Aberdeen Boulevard-Third Floor, Aberdeen Proving Ground, MD 21005-5001; or e-mailed to usarmy.apg.atec.mbx.atec-standards@mail.mil.

FONTAINE.RAYMO
ND.G.1228612770 Digitally signed by

MICHAEL J. ZWIEBEL
Director, Test Management Directorate (G9)

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Forward comments, recommended changes, or any pertinent data which may be of use in improving this publication to the following address: Range Infrastructure Division (CSTE-TM), U.S. Army Test and Evaluation Command, 2202 Aberdeen Boulevard, Aberdeen Proving Ground, Maryland 21005-5001. Technical information may be obtained from the preparing activity: Commander, U.S. Army Aberdeen Test Center, ATTN: TEDT-AT-WFE, Aberdeen Proving Ground, Maryland 21005-5059. Additional copies can be requested through the following website: http://www.atec.army.mil/publications/topsindex.aspx, or through the Defense Technical Information Center, 8725 John J. Kingman Rd., STE 0944, Fort Belvoir, VA 22060-6218. This document is identified by the accession number (AD No.) printed on the first page.